10

Electric Railway Traction

High Tension Direct Current

ALTHOUGH efficient service is being obtained from high-tension single-phase electrified systems in certain Continental countries and in North America, there appears to be a definite turn in other parts of the world towards the use of direct current with a line voltage of 3,000. The first installation of this type was the Harlowton-Avery section of the Chicago Milwaukee, St. Paul & Pacific Railroad, which was converted from steam in 1915, and was followed by a portion of the Othello-Tacoma division of the same railroad in 1919. Outside of North America the first example of this system was the Paulista Railway in Brazil, which was electrified by American firms in 1924, and the first European conversion was the Pajares incline on the Norte, in Spain, which dates from the same year. Curiously enough, much pioneer work on the Continent was done by the Italian State Railways, although the engineers of that system had always expressed great satisfaction with the operation of the extensive three-phase network in Piedmont and Liguria. Throughout the world there are now approximately 2,250 route miles of steam line electrified on this system, with a track mileage of approximately 3,100. In addition, a further 350 route miles are now under conversion.

Until recently, direct current systems were at a disadvantage compared with alternating current forms in so far as the converting equipment was concerned, but the astounding success of the mercury arc rectifier in providing an efficient and economical converting plant has shifted the balance to some extent. High-tension current requires the minimum of substations, and the progress made in traction motor design during the last decade permits of armatures being wound for 1,500 volts without any doubt as to their performance being necessary It has been claimed that the requirements of transmission, contact lines, and rolling stock have been met more completely with high-tension d.c. than with either single-phase or three-phase systems, but each type was originally developed to meet a given set of conditions, and with certain technical and economical combinations one or other of the three available systems can show to advantage over the other two. It appears to be fairly certain that 3,000 volts does not form the economical limit for d.c. systems, and the advances made in the last two or three years seem to indicate that 20,000 volts is well within the range of possibility. Careful estimates for a line with intensive traffic showed that the electrification cost with 20,000 volts would be only 80 per cent. that of a 3,000-volt system, but that the operating costs would vary from equality to 5 per cent. more. Reliable data on extra high-tension line voltages should be forthcoming within the next two or three years, for an experimental track with a line pressure of 20,000 volts is now under construction in Eastern Europe. The difficulties standing in the way of electrification to-day are financial rather than technical, and any imminent possibility of 20,000-volt direct current proving practicable might tend to increase the hesitation which is still felt in some quarters as to the desirability of electrification in general. But action might be postponed indefinitely if this consideration were allowed to prevail in cases where electric operation could show up to advantage, and great benefits would thus be lost. While not overlooking such possibilities altogether, it is usually advantageous to push forward with a policy more in keeping with present conditions.

Standardisation

STANDARDISATION, like charity, occasionally covers a multitude of sins. It is easy to permit a programme of standardisation to go beyond reasonable limits, and the objections which have been frequently raised as to its retarding effect on progress in design have not always been without cause. The benefits to be realised from the adoption of parts which are common to a number of locomotive classes are certainly not less in electric stock than they are in steam engines, and they are obtained more easily and with a limiting point which is much more clearly defined. Typical examples of well thought out programmes in this country are those applied to the electric stock of the Southern Railway and to the Underground system of the London Passenger Transport Board, in which the power equipment by several makers includes a number of standard components. The completion of negotiations between two big British manufacturers for the exchange of information on the subject of traction motors was recorded on page 826 of this Supplement for May 4, when the Southern Railway placed an order with the English Electric Company for 136 traction motors.

On another page of this issue we publish an article by Signor Bianchi of the Italian State Railways on the work which has been done in Italy on the standardising of the electrical and mechanical equipment of the locomotives for the 3,000 volt direct current lines. The completeness with which the components have been standardised over locomotive types used for all classes of traffic except shunting is reminiscent of what has been done on the 11,000-volt single-phase stock of the Pennsylvania Railroad, particulars of which were given in this Supplement for November 17, 1933. In both instances the same armature has been used for nose-suspended and quill-drive twin motors, and other constituents which are common to two or more classes are individual axle drives, stators, master controllers, resistances, pantographs, contactors, auxiliary machines, wheel centres and tyres, carrying bogies, axleboxes, and brake blocks, without detriment to the locomotive performance. In addition to the saving in cost of manufacture and maintenance resulting from the adoption of parts of similar design, the drivers do their work more efficiently, as the control apparatus on the locomotives does not differ between one class and another. Not every standardisation programme incorporates manufacture to tolerance limits which permit of interchangeability between all the locomotives concerned, but in our view the full benefits of standardisation cannot be reaped unless such construction forms one of the main features of the programme.

THE STANDARDISATION OF HIGH-TENSION D.C. LOCOMOTIVES IN ITALY

Four types have been designed to handle all classes of traffic over the 3,000-volt direct-current lines

By G. BIANCHI, of the Department of Locomotives and Rolling Stock, Italian State Railways

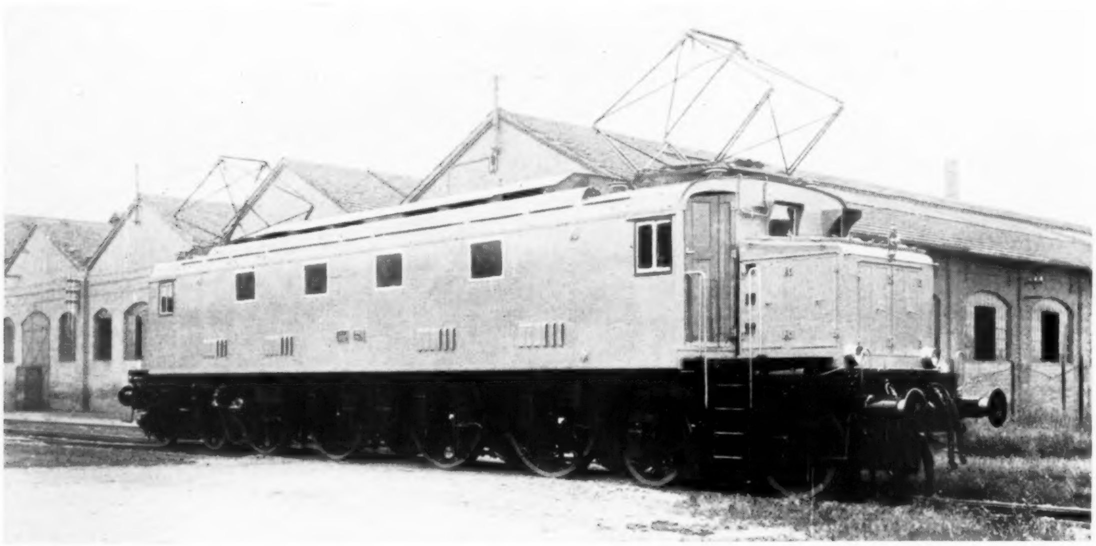


Fig. 1—New 3,750 h.p. high-speed electric locomotive, Italian State Railways

FOLLOWING upon the satisfactory results obtained from the electrification at **3,000** volts direct current of the Foggia-Benevento-Naples main line, carried out in **1927-28** and **1930-31**, the Italian State Railways authorities some time ago decided to adopt this system for view of the magnitude of the operation of these lines it is obvious that well-thought-out locomotive designs are of great importance, especially as only about **37** per cent. of the total operating expenses are due to fixed installations, the remaining **63** per cent, representing the cost of

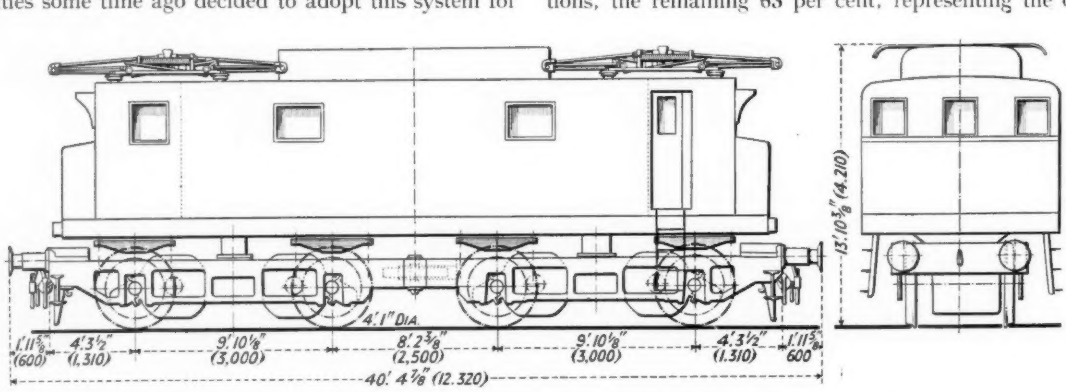


Fig. 2—Diagram of light duty locomotive for 3,000-volt direct-current lines

future conversion work in districts other than that covered by the three-phase network in Piedmont and Liguria, and a large part of the general conversion scheme* will be on this principle. A commencement has already been made in the conversion of over **860** route miles of line, and in electric energy and the operation and maintenance of the rolling stock.

Electric Locomotives

Four classes of locomotive have been designed to work all the traffic, apart from shunting, on the present and future high-tension direct-current lines, and of these, three

* Detailed in the *Electric Railway Traction Supplement* for May 4.—Ed.

are now in service. The fourth type, a double-bogie machine classified as **E.424**, which is represented by Fig. 2, will shortly be put into service for branch lines and light traffic. The other three types, classes **E.626** **E.326**, and **E.428** are now in main-line service, and are shown respectively in Figs. 3, 5, and 1. Main particulars of all classes are included in the accompanying table.

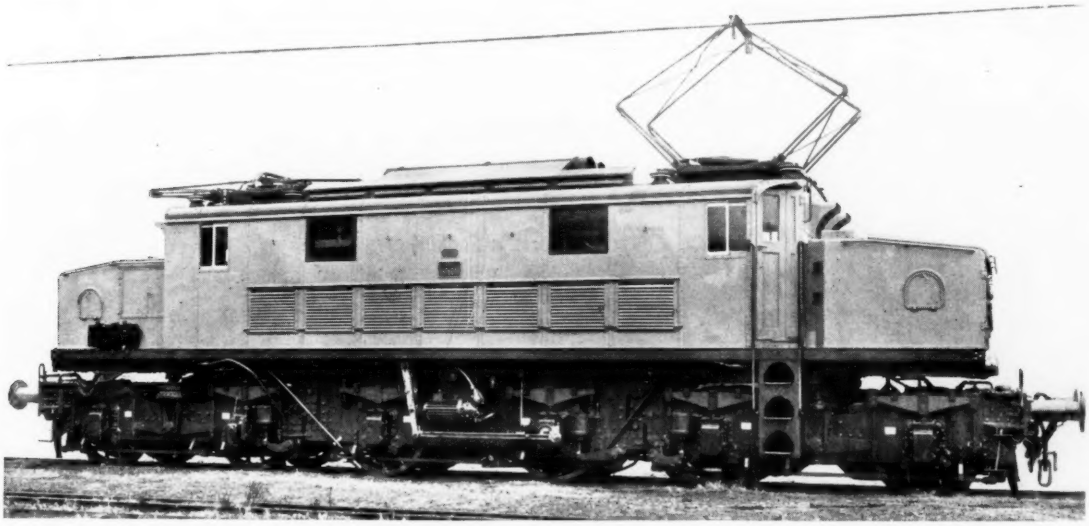


Fig. 3—Triple-bogie 2,915 h.p. heavy goods locomotive, Italian State Railways

DATA RELATING TO THE 3,000-VOLT D.C. ITALIAN STANDARD LOCOMOTIVES

	Class of Locomotive			
	E. 424	E. 626	E. 326	E. 428
Total weight in w.o., tons ...	70·5 (72)	94·3 (96)	110 (112)	126 (128)
Wheel arrangement	Bo+Bo	Bo+Bo+Bo	2-Co-2	2-Bo+Bo-2
Maximum axle load, tons ...	17½ (18)	15½ (16)	19 (19·5)	18 (18·7)
Total length, ft. ...	40 (12·2)	49 (14·9)	53 (16·15)	62 (18·8)
Diameter of driving wheels, in. ...	49 (1,250)	49 (1,250)	74 (1,880)	74 (1,880)
Number of motors	4	6	3 twin	4 twin
Total output (h.p. on hourly rating)	1,880	2,915	2,915	3,750
Maximum speed, m.p.h.	56 (90)	56 (90)	93 (150)	93 (150)

NOTE.—Figures in brackets are metrical equivalents.

An important feature of these locomotives is that both the mechanical and electrical parts have been standardised as far as possible. Over the four classes there are only two kinds of axles, gears and gear-boxes, and axle bearings; one type of leading truck; and one type of quill drive for the high-speed locomotives. The brake components are largely interchangeable between all classes.

As regards the electrical apparatus, standardisation has been reached in a most complete manner. The same type of motors (single or twin), armatures, contactors, master controllers, resistances, air compressors, and motor-generator sets, have been adopted for all four types. The complete locomotive designs have been worked out by a special office of the Italian State Railways, which was able to take advantage of the valuable experience obtained from operating previous locomotives.

The aim of the standardisation has been not only to reduce the first cost but also the operating costs. It has been found in this connection that the repairs bill of locomotives having different electrical apparatus and that of similar locomotives having both mechanical and electrical apparatus perfectly interchangeable may be in the ratio of 3 to 1, when taken over a large number of units. It has also been found that the crew can assure better and safer service if all locomotives are fitted with the same apparatus. The standardisation also permits a saving in the number of locomotives required for a certain amount of traffic, as it is possible to reduce considerably the overhaul period.

Light Duty Locomotive

The mechanical part of the locomotives of class E.424 does not present any special features. The two trucks are connected by means of a spherical coupling in order to transmit the tractive effort from one to the other. The cab is supported on the trucks by means of spherical pivots, one of which has a small amount of longitudinal play.

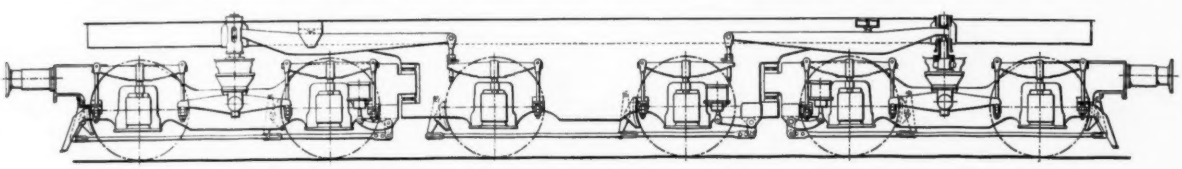


Fig. 4—Truck layout of heavy goods locomotive with nose-suspended motors

As in other types of locomotives, special attention has been paid to the arrangement of the electrical equipment

in order to keep cable connections as short as possible, avoiding any unnecessary crossing and giving freedom of access for inspection and maintenance. The central part of the cab contains all the high-tension equipment, and is closed by a mechanically-interlocked door. A side gangway allows passage from one driving compartment to the other, and a central gangway in the interior of the h.t. compartment facilitates inspection and maintenance of the control gear. Two electrical combinations are obtained by connecting the four motors in series, or in two groups of two motors in parallel. In addition to these two principal combinations, two others may be obtained by weakening the motor fields through the insertion of an inductive resistance in parallel with the excitation circuit of the main traction motors.

These locomotives are intended to be used both for freight and passenger trains at speeds not exceeding 56 m.p.h. According to the gear ratio the one-hour tractive effort at the wheel rims is 20,000 lb. at 28 m.p.h. (freight), and 12,000 lb. at 47 m.p.h. (passenger).

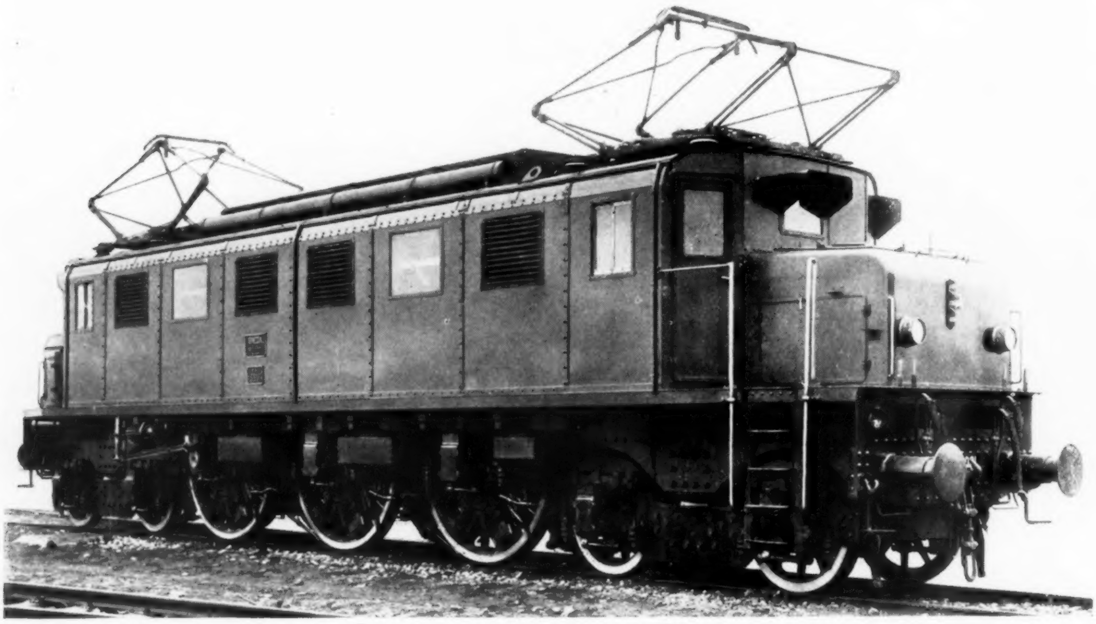


Fig. 5—Direct-current express locomotive of 2,915 h.p., Italian State Railways

Main-line Goods Locomotive

The triple-bogie, six-motor locomotives of class E.626 have been in service since 1927, and have given a satisfactory performance. The chassis arrangement of these locomotives, as shown in Fig. 4, consists essentially of

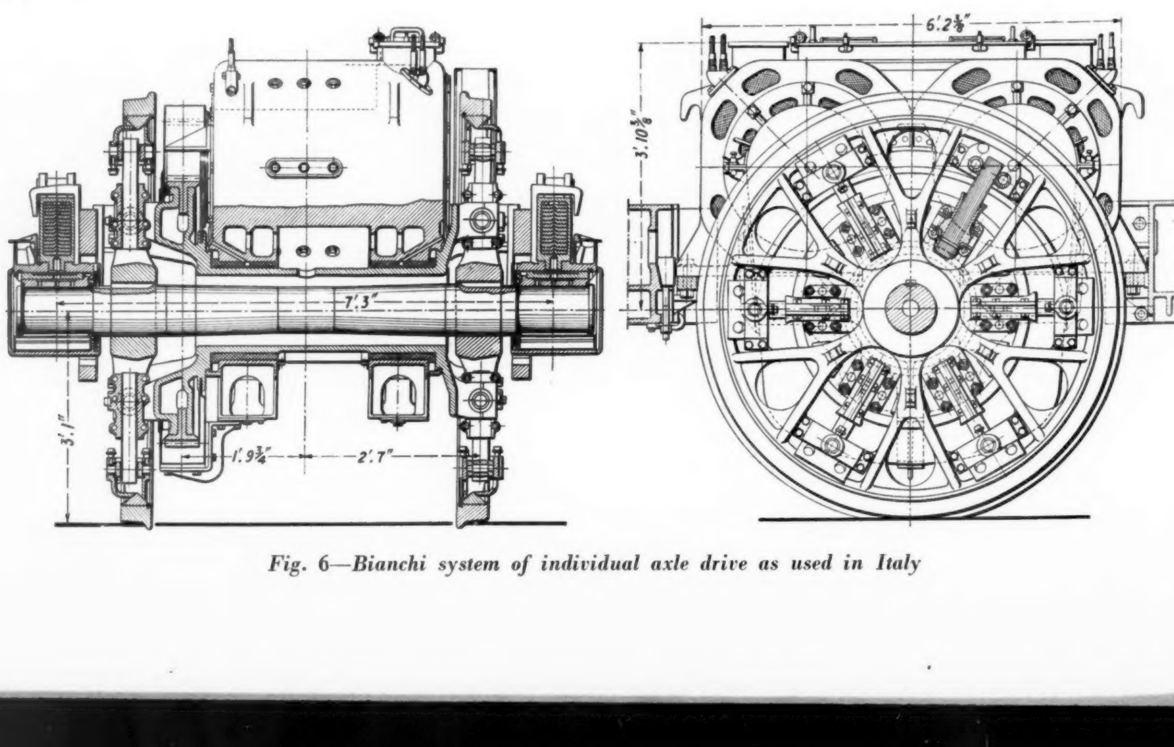


Fig. 6—Bianchi system of individual axle drive as used in Italy

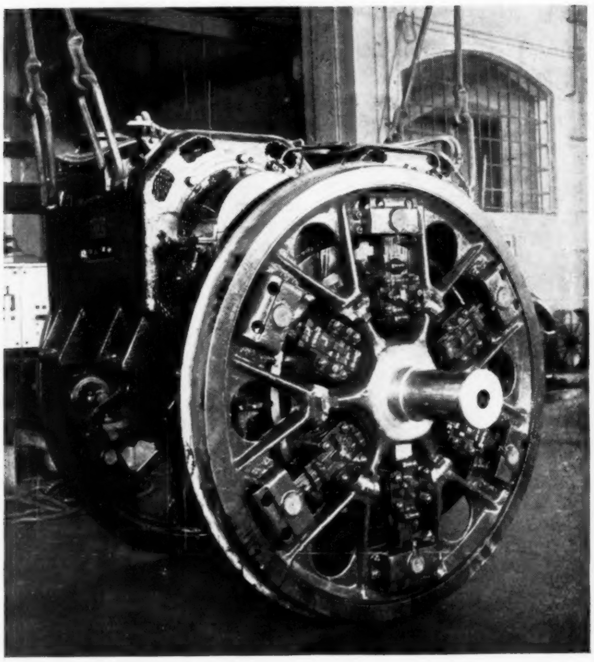


Fig. 7—Bianchi drive with twin-armature motor

three four-wheeled trucks, the central one having the side frames extending over the two side trucks. The suspension of the locomotive is obtained by means of equalising beams which ensure a uniform weight on each axle. The alignment of the first and third truck in relation to the central one is obtained by means of two supports sliding in two vertical cylinders fixed on the frame of the central truck, and riding on rollers on a double inclined plane contained in a case filled with grease and fixed to the bolsters of the outer trucks. In addition to this arrangement there is a double spring which adds a thrust of 1,500 lb., and the total thrust is about 5,000 lb.

The arrangement of the electrical apparatus in the interior of the locomotive is similar to that incorporated in class E.424. Three combinations are obtained by connecting the six motors in series, in two groups of three motors in parallel, and in three groups of two motors in series. In addition to these three groupings, three others may be obtained by weakening the field through the insertion of a suitable inductive resistance in parallel with the excitation circuit.

This type of locomotive has proved to be suitable for passenger as well as for freight service. In freight service the tractive effort (one-hour rating) at the wheel tread at 25 m.p.h. is 40,000 lb., and in the passenger service the effort at the one-hour rating is 19,000 lb. at 56 m.p.h. Main dimensions other than given in the table are as follow: rigid wheelbase, 8 ft. 1 in.; total wheelbase, 37 ft. 11 in.; maximum width, 9 ft. 8 in.; maximum height with pantographs locked down, 13 ft. 7 in.

Main-line Passenger Locomotive

These locomotives have been constructed to haul express trains having a weight of 450 tons up gradients of 1 in 60 at a speed of 57 m.p.h., and at a maximum speed of 93 m.p.h. on the level. The mechanical portion is composed of a main frame, supported by three driving axles with a carrying truck at each end. The transmission of the torque from the twin motors to the driving wheels is affected by a quill in conjunction with a system of flat, laminated springs. The spring bands, which may be seen in Figs. 6 and 7, are prolonged beyond the slot of the leaves and are so shaped as to form a support for the leaves when the latter deflect under the transmitted forces. The spring bands are articulated with respect to the quill, so as to permit of an inclination between that member and

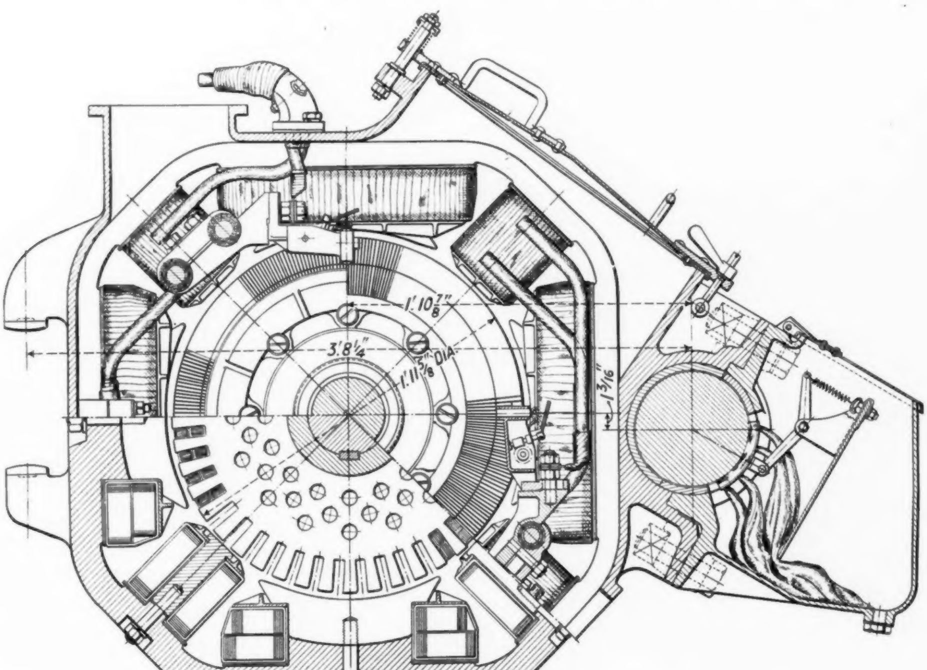


Fig. 8—Direct-current nose-suspended traction motor wound for 1,500 volts. This motor is used for light duty and heavy goods locomotives, and the armature is identical with that used in the spring-supported twin motors used in the Italian express locomotives

the driving axle. This system, known as the Bianchi drive, has been successful over four years of service in 32 high-speed locomotives, and has been adopted as a standard for all the express locomotives now in course of construction.

The twin motors employed in these locomotives have the same armatures as the nose-suspended motors employed in the Bo+Bo and Bo+Bo+Bo locomotives.

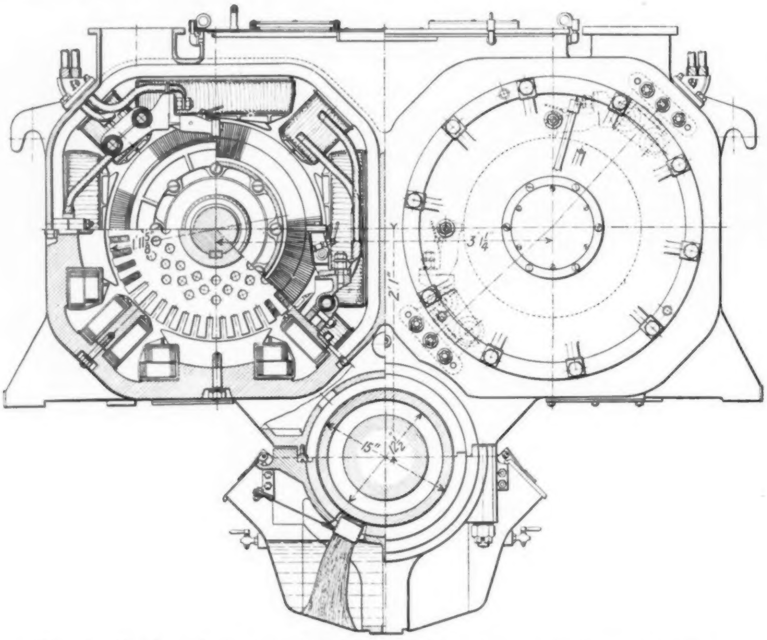


Fig. 9—Section through twin-armature spring-supported traction motor, Italian State Railways

The frame of the motor has large covers which permit of easy access to the commutator and brushes from the side gangway of the cab, even when the locomotive is running. The electrical equipment of the locomotive is of the standard type. These locomotives are now in service on express trains over the Florence-Bologna Direttissima line, and on the Foggia-Naples division.

High-speed Passenger Locomotive

This type of locomotive may be regarded as an enlargement of class E.326, but with four driving axles instead of three. The mechanical part consists of two steel plate frames, connected by means of a ball joint of the same type as that employed in the Bo+Bo locomotives of class E.424. The cab is supported by means of spherical centre bearings and four flat springs, and the quill drive is of the same type as that illustrated in Figs. 6 and 7.

At the moment, the first batch of these engines is running on the Direttissima, but on the completion of electrification from Florence to Rome and on to Naples, which is anticipated for the end of 1935, they will be put on to haul express trains up to 670 tons in weight between these points, encountering on the journey grades up to 1 in 60, which will be surmounted at a speed of 57 m.p.h. On the level the maximum rate will be 93 m.p.h.

Standard Electric Apparatus

As previously stated, both nose-suspended and twin motors have the same armature, field coils and commutating coils. The laminated armature core is 23½ in. diameter and 13½ in. long. The armature winding has 630 conductors having a section of 0·04 sq. in., and is divided into 45 slots with series windings. There are 315 bars on the commutator. The motor is rated for one hour at 350 kW. at 1,500 volts, and 750 r.p.m. In Fig. 8 is shown the nose-suspended motor employed in the Bo+Bo and Bo+Bo+Bo locomotives, and in Fig. 9 is shown the twin motor adopted in the 2-Co-2 and

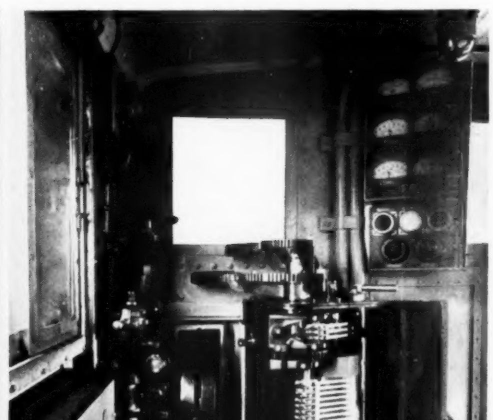


Fig. 10 (above)—Main control room of Italian d.c. locomotives

Fig. 11 (right)—Driving position of electric locomotives

Fig. 12—Express locomotive of the 2-Co-2 type at the head of a train on the Naples-Foggia line

2-Bo+Bo-2 locomotives. The armatures of all motors run in roller bearings.

For auxiliary services a **3,000**-volt motor of **10** kW. capacity has been incorporated, both for the air compressors and motor-generator sets. The armature of this motor has a series winding distributed in **31** slots, and the commutator has **279** bars. The laminated core is **13½** in. diameter and **5¾** in. long, and the motor runs at **1,100** r.p.m.

The contactors for effecting the grouping of motors are cam-operated, the cams themselves being controlled pneumatically. The contactor-group unit is common to the four locomotive classes. Three contactors in series are used in all locomotives as main-circuit breakers, and similar contactors are used to cut out the starting resistances. The arrangements of the main control room and the driving position are the same in all types, and are depicted respectively in Figs. **10** and **11** at the bottom of the previous page. As may be seen from Fig. **13** these electric locomotives have only one door into the driving compartment from the outside.

A comparison of the operating costs of some locomotives whose electrical apparatus is of five different makes, and an equal number of standard locomotives, has enabled the advantages of standardisation to be appreciated. The time required for an ordinary maintenance job which averaged **0·6** man-hours for every **1,000** locomotive miles of running before standardisation has been reduced to **0·18** man-hours with locomotives all of the standard type. The frequency of locomotive failures, which was about five for every **100,000** locomotive-miles, has fallen since standardisation to **1·8**. These results are due chiefly to the greater simplicity of the electrical and mechanical apparatus of the standard locomotives, as well as to the fact that the drivers become better acquainted with apparatus which is repeated in all types of locomotives.

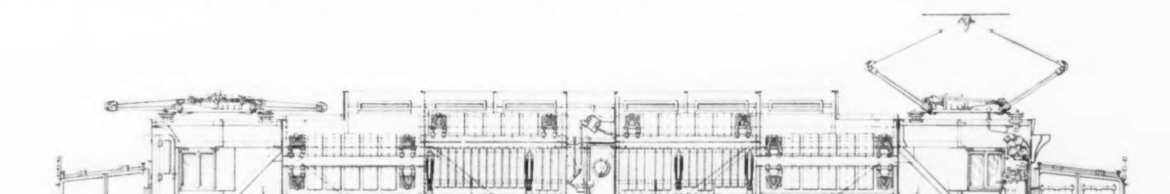


Fig. 13—General arrangement of the 3,750 h.p. electric locomotives, Italian State Railways

THE ADHESION EFFICIENCY OF ELECTRIC LOCOMOTIVES WHEN BRAKING

A short study of the effect of different brake arrangements on the axle loads during retardation

By F. WHYMAN, B.Sc. (Tech.), A.M.I.E.E.

IT is well known that the most satisfactory manner of braking a locomotive wheel is by the shoe arrangement known as the clasp brake, which embodies a shoe on each side of the wheel, applied with equal force. In large electric and steam locomotives it is not always possible to accommodate two brake shoes and the attendant rigging on each wheel, and a comparison of the efficiencies of alternative arrangements brings to light some interesting points.

Variation of Rail Reaction due to the Layout of Brake Shoes

Referring to Fig. 1, three arrangements of brake shoes are indicated, and in each case, a retarding effort T is being produced. The forces acting on the wheel are shown for each case, P being the sum of the spring pressure and dead weight acting on the axle. It is obvious from Fig. 1

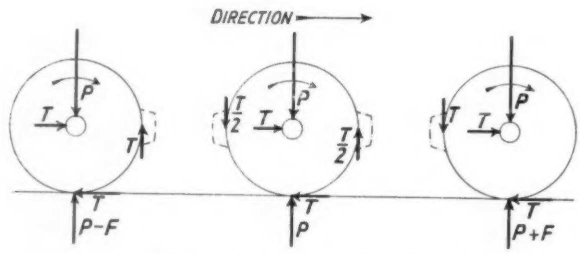


Fig. 1—Braking forces on a wheel with different shoe layouts

that the reaction between wheel and rail is dependent upon the arrangement of the brake shoes. When only one side of a wheel is braked, the total retarding force, F, exerted by the rail on the wheel is added to or subtracted from the vertical reaction between rail and wheel, depending on whether the shoe is behind or ahead of the wheel.

Effect on Rail Reactions of the Various Axles During Braking

To illustrate the variation of the rail reactions of the various axles during braking with different arrangements of brake shoes and spring system, the results shown in Fig. 3 have been worked out for otherwise identical locomotives. The following figures give the general characteristics of the locomotive, which is the same unit as was considered when dealing with the adhesion characteristics of nose-suspended motor drives in the last issue of this Supplement, and which is illustrated in Fig. 2.

Overall wheelbase	30·916 ft.
Truck wheelbase	9·25 ,,
Distance between two middle axles	12·416 ,,
Truck centres	21·666 ,,
Total weight of locomotive	67·0 tons.
Normal rail reaction of each axle	16·75 ,,
Radius of driving wheels	2·00 ft.
Height of drawbar above rail	2·875 ,,
Height of centre pivot of truck above rail	3·55 ,,
Deadweight per axle	3·00 tons.

The examples in Fig. 3 have been worked out to show the individual rail reactions of the different axles when the locomotive is exerting a braking effort of 25 per cent. of its deadweight, *i.e.*, 16·75 tons, and they take into account the overturning moment due to the exertion of retarding effort at the height of the buffing gear above rail level.

The diagrammatic sketches of the different spring and brake shoes systems are easily understood. The first example denotes a two-bogie locomotive in which clasp brakes are fitted to all wheels. The springs of the two axles of each bogie are equalised and the bogies are provided with end bearers in contact with the locomotive body. The second example represents an identical locomotive with the exception that the axles of each bogie are not equalised. For each example, the lowest rail reaction is indicated in the column on the extreme right as a percentage of the normal rail reaction of 16·75 tons. This percentage column can be taken as a ratio of the retarding efforts possible with each arrangement without slipping.

As an illustration of the method of computation, the detailed calculation of the third example in Fig. 3 is given below :—

Let P_1 = spring pressure of each trailing bogie axle.
,, P_2 = ,, ,, ,, leading ,,

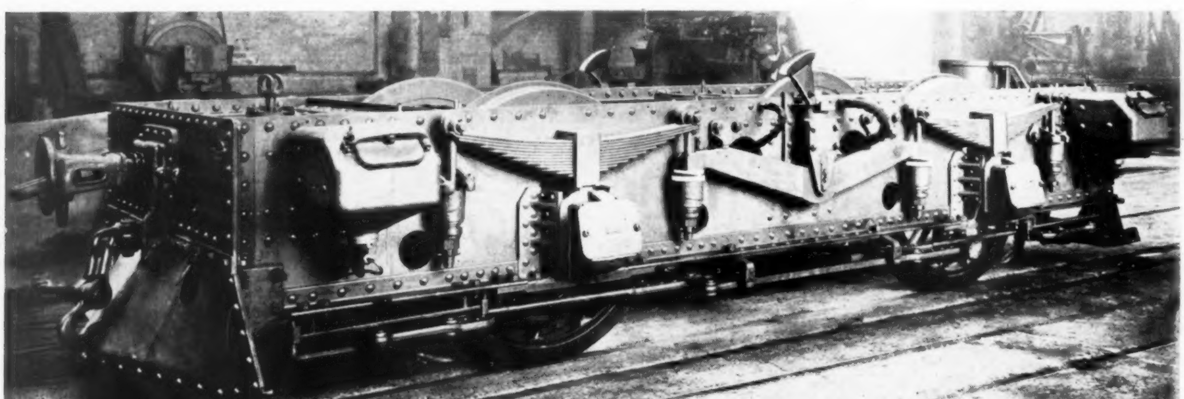


Fig. 2—Motor bogie of South African Railways electric locomotive referred to in this article

The springborne portion of the locomotive weight is

$$67 - 12 = 55 \text{ tons.}$$

Then $2P_1 + 2P_2 = 55$

$$P_1 + P_2 = 27{\cdot}5 \quad \ldots\ldots\ldots\ldots \quad (1)$$

Reading from left to right, with the direction of motion left to right, the rail reactions of the various axles must be,

$$(P_1 + 3 + 4{\cdot}19),\ (P_1 + 3 - 4{\cdot}19),$$
$$(P_2 + 3 + 4{\cdot}19),\ (P_2 + 3 - 4{\cdot}19)$$

which are :—

$$(P_1 + 7{\cdot}19),\ (P_1 - 1{\cdot}19),\ (P_2 + 7{\cdot}19),\ (P_2 - 1{\cdot}19).$$

As the locomotive as a whole is in equilibrium, the sum of the moments of the rail reactions of all the axles about the centre of the locomotive must be equal to the clockwise moment

$$16{\cdot}75 \times 2{\cdot}875 \text{ (drawbar height)} = 48{\cdot}2 \text{ tons-feet.}$$

Therefore

$$(P_2 - 1{\cdot}19 - P_1 - 7{\cdot}19)\,15{\cdot}458 + (P_2 + 7{\cdot}19 - P_1 + 1{\cdot}19)\,6{\cdot}208 = 48{\cdot}2.$$

$$\therefore P_2 - P_1 = 5{\cdot}8 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

From (1) and (2) it follows that $P_1 = 10{\cdot}85$ tons, and $P_2 = 16{\cdot}65$ tons.

The various rail reactions are, therefore, as follow :—

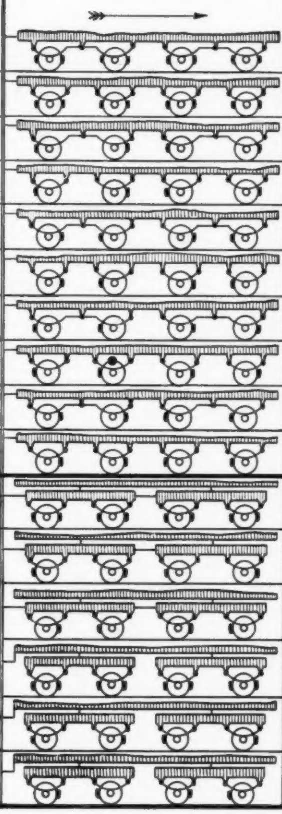
$$(10{\cdot}85 + 7{\cdot}19),\ (10{\cdot}85 - 1{\cdot}19),$$
$$(16{\cdot}65 + 7{\cdot}19),\ (16{\cdot}65 - 1{\cdot}19),$$

which are :—

18·04 tons, 9·66 tons, 23·84 tons, 15·46 tons.

As the normal rail reaction is 16·75 tons and the lowest reaction above is 9·66 tons

$$\text{then} \quad \frac{9{\cdot}66}{16{\cdot}75} \times 100 = 57{\cdot}6 \text{ per cent.}$$



%	SPRING PRESSURES–TONS				ARRANGEMENT	RAIL REACTIONS				%
91·8%	12·64	12·64	14·86	14·86		15·64	15·64	17·86	17·86	93·4%
90·2%	12·41	13·21	14·29	15·09		15·41	16·21	17·29	18·09	92%
78·9%	10·85	10·85	16·65	16·65		18·05	9·65	23·85	15·45	57·6%
74·4%	10·24	12·33	15·17	17·26		17·44	11·13	22·37	16·06	66·5%
95%	14·43	14·43	13·07	13·07		13·23	21·63	11·87	20·27	70·8%
94%	14·57	14·09	13·41	12·93		13·37	21·29	12·21	20·13	73%
61·3%	8·44	8·44	19·06	19·06		15·64	15·64	17·86	17·86	93·4%
53·4%	7·35	11·18	16·32	20·15		14·55	18·38	15·12	18·95	86·8%
77·5%	16·84	16·84	10·66	10·66		15·64	15·64	17·86	17·86	93·4%
72·8%	17·48	15·25	12·25	10·02		16·28	14·05	19·45	17·22	83·8%
81%	11·14	16·36	11·14	16·36		14·14	19·36	14·14	19·36	88·4%
50·4%	6·94	20·56	6·94	20·56		14·14	19·36	14·14	19·36	84·4%
88·4%	15·34	12·16	15·34	12·16		14·14	19·36	14·14	19·36	84·4%
74·8%	10·8	17·22	10·28	16·7		13·8	20·22	13·28	19·7	79·2%
44·2%	6·6	21·42	6·08	20·9		13·8	20·22	13·28	19·7	79·2%
90·8%	15·0	13·02	14·48	12·5		13·8	20·22	13·28	19·7	79·2%
NORMAL SPRING PRESSURE = 13·75						NORMAL RAIL REACTIONS = 16·75				

Fig. 3—Variation in rail reaction with different braking arrangements

General Conclusions

The figures given in Fig. 3 show that the least disturbance of rail reaction is obtained either when clasp brakes are fitted to each wheel, or when the brake shoes of the wheels of a bogie are on the same side of the axle. Clasp brakes will obviously be more smooth in operation, as the various spring pressures are considerably less disturbed than in other cases, and they are universal in multiple-unit stock, if not in locomotive practice.

It will be appreciated from the foregoing remarks that where difficulty is experienced in fitting clasp brakes to the locomotive wheels, careful thought on the above lines is necessary to arrive at the most satisfactory alternative. An unfortunate choice of braking system may result in slipping of certain wheels with little more than half the anticipated retarding effort of the locomotive. In addition to preventing the development of the full braking effort of which the locomotive should be capable, the slipping of certain axles very quickly produces flats on the tyres, which necessitates expensive dismantling and turning up of the tyres.

Publications Received

Relays and Feeder Protective Systems.—The characteristics of relays for use in protective systems requiring a high degree of sensitivity are dealt with in a useful pamphlet published by A. Reyrolle & Co. Ltd., Hebburn-on-Tyne. The Reyrolle rotary type of sensitive relay is made in a standard pattern for systems in which an instantaneous relay is desired, and also with a compensating device for systems requiring such a feature. Directional over-current and reverse-current relays by the same maker are described in a separate pamphlet. Yet another brochure describes the Reyrolle interlock feeder-protective system, the characteristics of which approach the ideal of a combination of the Merz-Price system.

Power Consumption on Swiss Federal Railways.—The major portion of the electric power used by the Swiss Federal Railways is obtained from their own power stations at Ritom, Amsteg and Goeschenen in the central part of Switzerland, and Barberine, Vernayaz, Trient and Massaboden in the western district. In 1933, the production of single-phase current in these stations amounted to 439,400,000 kWh., and an additional 58,000,000 kWh. of three-phase current was generated by the stations at Amsteg, Vernayaz and Massaboden during the summer months when the volume of water was at its highest. This additional current was furnished to private industry at low prices. In 1933 the Federal Railways consumed 514,000,000 kWh., of which 247,000,000 kWh. were consumed in the six months comprising the summer and spring season.

MERCURY ARC RECTIFIERS—IV

Notes on the construction, application, and performance of the glass-bulb type of rectifier as used in heavy railway traction service

THERE can be little doubt that the utilisation of mercury rectifiers has been retarded in the past by the prejudice of engineers against depending upon a glass bulb for power service. Apart from the undeniable mechanical fragility of glass, compared with what are generally considered engineering materials, many potential users of rectifiers appear to have been obsessed by the idea that glass-bulb rectifiers would burn out after a time, like a filament lamp. Admittedly glass is relatively fragile, but a rectifier bulb is easily protected from mechanical injury to which, incidentally, it is no more vulnerable than the metal parts of many delicate mechanisms. There is, in fact, no basis for any feeling that glass-bulb rectifiers are not thoroughly practical and reliable engineering products. Convincing evidence as to their longevity is now available, but it is still impossible to say what may be regarded as an average life, for the simple reason that the majority of glass rectifier banks are still in service with the original bulbs.

A number of Hewittic rectifier bulbs have already been in use for nearly 10 years, and actually 96 per cent. of the total number supplied to date are still in service. Many of those old-timers are, of course, relatively small units in lighting or other reasonably steady service, but there is no reason to suppose that the larger units now employed in traction and other severe service will be any less satisfactory. In a set of 52 glass bulbs which have been working in heavy traction service in this country for periods varying from 9 to 16 months, only one bulb has been returned to the makers for re-evacuation, and as the temporary loss of one bulb does not impair the working capacity of a normal set, no interruption of traffic was occasioned. Where a bank of glass rectifiers is employed, the provision of a spare bulb for emergency replacement is a reasonable and inexpensive precaution, quite in line with the provision of spares in other engineering equipment.

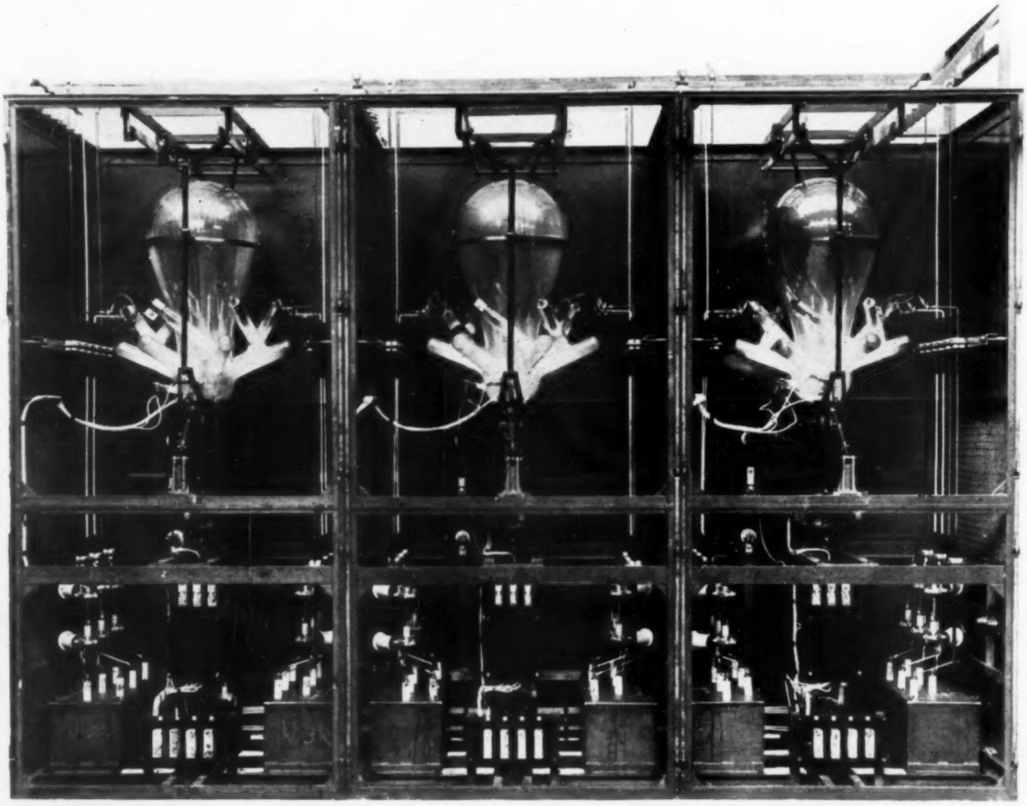


Fig. 1—Half of 1,200 kW. six-bulb Hewittic mercury arc rectifier set, L.M.S.R.

Advantages of Glass Bulbs

An outstanding advantage of the glass-bulb rectifier is that it is always ready for immediate service, no matter how long it has been standing idle. The bulb is evacuated and sealed by the makers, and the vacuum is fully maintained through a service life which is evidently of the

Fig. 2—Hewittic rectifier bulb as used on the Lancashire electrified lines, L.M.S.R.

order of tens of thousands of hours, if not longer. No vacuum pump is required, and normally a small fan for the air-cooling of the bulb is the only moving part. For outputs exceeding **500** amp. per bulb at **600** volts, *i.e.*, over **300** kW. per bulb, the use of a water-cooling tube extending up through the cathode to the centre of the bulb may be advisable, in order to reduce the size of the bulb and fan, but fan-cooling alone is standard practice in the glass-bulb rectifiers hitherto employed for outputs up to about **500** amp. at **600-660** volts. It may here be mentioned that the Gleichrichter Gesellschaft m.b.H., Berlin, associated with the firm of Brown Boveri, has several **500** amp. bulbs in traction service which regularly carry overloads up to **25** per cent. for **20** min., and **900** amp. for a few seconds.

In addition to the advantages already mentioned, resulting in negligible depreciation and attendance, simplicity of equipment and completely static operation (excepting the cooling fan), glass-bulb rectifiers have all the advantages associated with the principle of rectification, including high and nearly constant efficiency from $\frac{1}{4}$ to $1\frac{1}{4}$ times their rated output; small no-load loss, resulting in economical operation on low load factor; easy applicability to any a.c. supply; freedom from synchronising difficulties; easy installation, without cranes or heavy foundations; ready adaptability to remote or automatic control; silent operation; and immunity from damage by any fault or short circuit in either the a.c. or the d.c. networks. Most of these general advantages are common to all mercury rectifiers, whether glass or metal enclosed, but the important distinction between the two types in point of maximum output per unit remains to be discussed.

Output Data

The greatest possible output from glass-bulb and metal-clad rectifiers respectively has still to be ascertained; doubtless the limits for each type will be gradually extended, but at **500** volts the present maximum currents are about **500** amp. for a glass bulb and **16,000** amp. for a metal-clad rectifier. For normal traction requirements, four or six glass-bulb rectifiers may be used in parallel where one metal-clad rectifier would suffice. The multiplicity of glass-bulb units is not necessarily a disadvantage. True, there is a greater number of pieces of apparatus, but the equipment is very simple, and the failure of one unit in a bank of glass-bulb rectifiers does not affect the continued operation of the others. In general, the unit capacity of rectifiers is not a limiting factor in traction service; a number of well-distributed substations of moderate kW.-capacity is generally the most efficient arrangement, and the easy remote control of rectifiers facilitates such subdivision. The fact that there is **6,000** kW. capacity in Hewittic glass-bulb rectifiers in the Evelyn Street substation of the Borough of Shoreditch—the largest glass-bulb rectifier substation in the world—is sufficient proof that the relatively low kW.-capacity of unit bulbs places no restriction on the use of glass-bulb rectifiers in heavy power service. From the operating standpoint, the risk of hot spots on the anodes and of backfiring is practically eliminated by the relatively low current on each anode.

The successful applications of Hewittic glass-bulb rectifiers on the Liverpool-Southport and Manchester-Bury

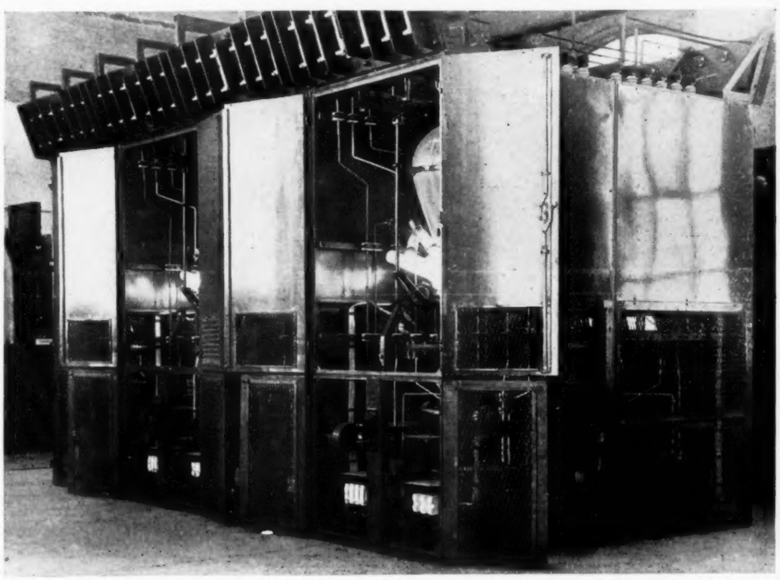


Fig. 3—Hewittic rectifier bank in Hillside substation, Liverpool-Southport line, L.M.S.R.

lines of the L.M.S.R. afford excellent examples of the simplicity, convenience and efficiency of this type of equipment, and its suitability for heavy traction service. Fig 1 shows half of a 1,200 kW. six-bulb Hewittic rectifier set installed at Radcliffe substation, where three banks make up a total capacity of 4,500 kW. Fig. 3 shows the 2,000-2,500 amp., 600-volt Hewittic bank at Hillside substation with some of the cubicle doors open.

The Wicky Dale and Hillside substations on the Liverpool-Southport line each contain eight rectifier bulbs fed

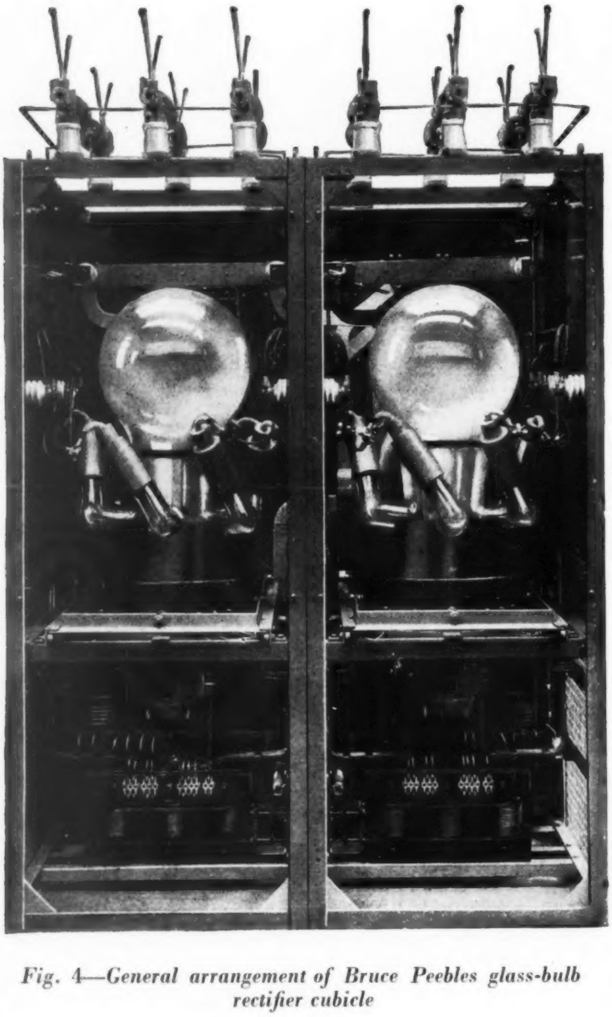


Fig. 4—General arrangement of Bruce Peebles glass-bulb rectifier cubicle

by a 3-phase/12-phase transformer from 7,500 volts, 25-cycle, 3-phase supply; and each substation has a normal d.c. output of 2,000 amp. at 600 volts (1,200 kW.), which can be raised to 2,500 amp. (1,500 kW.) for 2 hr., 4,000 amp. (2,400 kW.) for 10 min., and 6,000 amp. (3,600 kW.) momentarily. On the Manchester-Bury line, the d.c. traction supply is derived from an 11,000-volt, 50-cycle, 3-phase a.c. system through two glass-bulb rectifier substations, one at Victoria and one at Radcliffe, each substation containing 18 rectifier bulbs in three banks of six bulbs, each bank being capable of a continuous total output of 1,000 amp. at 1,200 volts (1,200 kW.), rising to 1,250 amp. (1,500 kW.) for 2 hr., 2,000 amp. (2,400 kW.) for 10 min., and 3,000 amp. (3,600 kW.) momentarily. At the Wicky Dale and Hillside substations each of the eight bulbs has a continuous output of 250 amp. at 600 volts, or 150 kW., while at Victoria and Radcliffe substations, with a higher line voltage, each of the bulbs has a continuous output of 167 amp. at 1,200 volts, or 200 kW.

An interesting feature of these installations, which were described in the issue of this Supplement for April 6 last, is that provision is made for increasing the line tension from 600 to 750 volts on the Liverpool-Southport line, and from 1,200 to 1,500 volts on the Manchester-Bury line whenever this may be desired, the only change required being an alteration of the transformer tappings. The easy practicability of increasing the d.c. voltage in this way should be borne in mind as one of the advantages of mercury-rectifier equipment, but, if it is proposed to make use of it, the original insulation should be proportioned to the ultimate working voltage.

Bulb Construction and Mounting

The principle of operation of a mercury rectifier is exactly the same whether the enclosing vessel be of glass or steel, but from the constructional standpoint glass offers the advantage of being an electrical insulator and of permitting all joints to be made by fusion, thus ensuring permanent maintenance of vacuum without the use of a pump. As will be gathered from Fig. 2, a modern rectifier bulb is a remarkable example of the glassworker's craft.

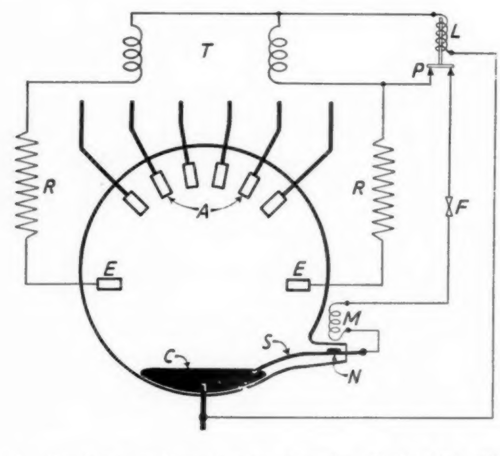


Fig. 5—Ignition and excitation circuits of English Electric type of glass-bulb rectifier

Its reliability in service, particularly as regards freedom from cracking, depends essentially upon the use of a glass which is unaffected by sudden local variations in temperature. The bulb shown in Fig. 2 is, of course, being carried upside down. Its normal position in service can be seen in Fig. 3, which shows bulbs in actual operation as indicated by the characteristic glow in the anode tubes and lower part of the bulb.

The pool of mercury forming the cathode rests at the bottom of the bulb, the expanded upper portion of which forms a chamber for the condensation of mercury evaporated from the pool by the heat of the arc. Cooling is effected by a fan driven by a vertical-shaft electric motor placed below the bulb; this fan draws air through the expanded metal sides of the enclosing cubicle and drives it over the surface of the bulb. The fan motor is clearly visible in Fig. 4, but the fan is hidden by the deflector which distributes air over the bulb.

Close above the mercury pool there are short radial

side tubes for the ignition and exciting anodes, which are further mentioned in connection with Fig. 5. Above these are the cranked side tubes containing the main anodes. Usually there are six anodes, connected independently to the terminals of a 6-phase rectifier, or to one of two sets of 6-phase busbars supplied from a 12-phase rectifier as in Fig. 6. Straight anode tubes can be used for very low voltages (less than 100 volts), but the cranked form, giving a sharp bend in the direction of the arc, is usually employed to remove the anodes from mercury spray and vapour which might cause backfire. For very high d.c. tensions (some thousands of volts), the anode tubes are cranked twice, but the form illustrated meets the usual traction requirements.

Alternative methods of mounting bulbs are shown in Figs. 3, 4, and 10. In each case the enclosing cubicle is of steel plate and sheet construction with full provision for ventilation. The bulb is carried by a frame which combines mechanical security of support with sufficient elasticity and cushioning to avoid any possibility of breakage by constraint. For the same reason, flexible leads are used for the electrical connections to the cathode and anodes. In large units, the bulb supports are specially designed to facilitate withdrawal of the bulb from the front or rear of the cubicle as the case may be. The a.c. busbars are placed at or near the top of the cubicle and the d.c. bars at the bottom. The equipment is generally assembled on the unit principle, each rectifier bulb having its own auxiliaries, switchgear and fuses; maximum security is thus obtained and the bank can be run with any desired number of units in service.

The form and mounting of the auxiliaries vary with different makers. The function of those provided with Hewittic rectifiers will be clear from the connection diagram, Fig. 6, and the neat manner in which they are accommodated in the cubicle is shown by Fig. 3. As another example, Fig. 4 shows a Bruce Peebles cubicle. In this illustration there can be seen, in the right-hand cubicle below the platform carrying the bulb carriage, the vertical-shaft fan motor; below that is the auxiliary transformer, with the excitation choke coil to the left and the absorption choke coil to the right. Above the rectifier bulb, to the left, there is a fan relay which shuts down the unit if the cooling fan ceases to operate. The horn-gap arresters at the top of the cubicle protect the main transformer windings against the possibility of voltage surges. The main transformer is placed outside the cubicle, or, if desired, outside the substation building. Measuring instruments and control switches may be mounted on the front of the cubicle, or on a separate panel, according to circumstances; and there is no difficulty in arranging for remote supervisory or completely automatic control.

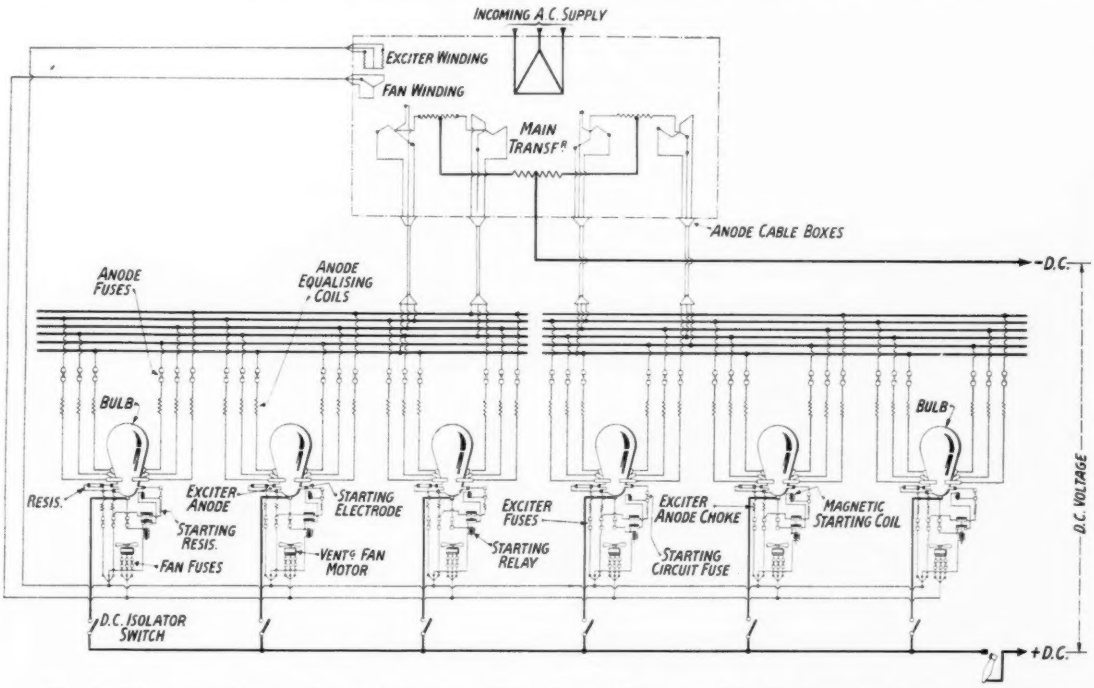


Fig. 6—Diagram of connections of six-phase Hewittic rectifiers served by 3-phase–12-phase transformer, Manchester-Bury line, L.M.S.R.

Operating Features

The circuit details and the methods of operation and control are very simple. So far as the operator is concerned, starting is effected by switching-on the high-tension a.c. supply, which may be done from any distance through a pilot wire circuit, or it may be accomplished automatically by a voltage relay, time-switch, or other means. Interlocks on the cubicle doors prevent the gear from being made live while the doors are open, and the doors from being opened while the gear is live.

Closing the h.t. supply brings the ignition and excitation circuits into action, thus striking an arc in the rectifier bulb and causing it to be maintained. The details of the ignition and excitation circuits vary with different makers, but may be explained by reference to Fig. 5, which relates to English Electric rectifiers. Closing the h.t. supply excites the secondary winding *T* of an auxiliary transformer which then sends current through the winding of an electromagnet *M*, a flexible strip *S*, the cathode mercury *C*, and back via *L*. The strip *S*, inside the

rectifier bulb, carries a small armature *N*, which is attracted by the external electromagnet *M*, lifting the tip of *S* out of the cathode mercury and striking a small arc between *S* and *C*. The arc thus formed is immediately transferred to whichever one of the electrodes *E* is positive at the moment, relatively to the cathode. Thereafter, an excitation arc is maintained between each of the anodes *E E* in turn and the cathode *C*, the combination *T, E, E, C* constituting a single-phase rectifier with current-limiting resistances or chokes at *R, R*. Directly the excitation arc is established, the current flowing through *L* is sufficient to lift the plunger and open the contact *P* in the ignition circuit, but the excitation arc continues to burn as long as the a.c. supply is maintained, thus ensuring that there is always a hot spot on the cathode even if the arc from the main anodes *A* be interrupted by grid control or by temporary removal of the d.c. load. An electromagnetically operated ignition device is also used in Hewittic rectifiers, successive excitation and de-energisation of the magnet causing a flexible connection to make and break contact with the cathode mercury. In Bruce Peebles rectifiers, however, the ignition arc is struck by the bending of a bi-metal contact strip when heated.

Once the excitation arc is established, the rectifier continues to operate as long as required, subject to automatic protection and manual or automatic voltage control as noted below. The protective gear associated with the Hewittic installation represented by Fig. 6 includes a quick-acting fuse in each anode lead and a high-speed reverse-current circuit breaker controlling the d.c. output; also, high-speed circuit breakers with overload release in the traction feeders. An isolating link is provided in each cathode lead; and in each anode lead there is an oil immersed equalising choke, the purpose of which is to secure equal division of load between the bulbs operating in parallel. Separate remote control is provided for each feeder and rectifier, and arrangements are made to indi-

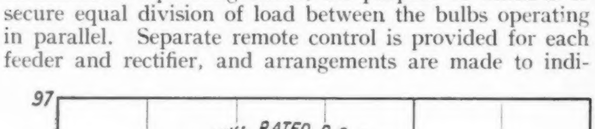


Fig. 7—Overall efficiency of glass-bulb rectifier, allowing for transformer, rectifier and auxiliary losses

cate at the control station the positions (on or off) of all switches and circuit breakers in the rectifier substation, also the readings of the substation voltmeters and ammeters. The precise arrangement of the controls can be varied to suit individual requirements, but the general principles remain the same. An interesting auxiliary in English Electric rectifiers is the use of choke coils on the rectifier, thus improving the efficiency at low loads.

Efficiency

The curves in Fig. 7 show overall efficiencies of Hewittic glass-bulb rectifier banks, taking into account the losses in the main transformers, rectifiers and auxiliaries. The particular equipments concerned are: (*a*) The 8-bulb banks for 2,000 amp. 600 volts d.c. output in the Wicky Dale and Hillside substations, Liverpool-Southport line;

Fig. 8—Six-phase grid-controlled English Electric rectifier

(*b*) the 6-bulb banks for 1,000 amp., 1,200 volts d.c. output in the Victoria and Radcliffe substations, Manchester-Bury line; and (*c*) the same banks as at (*b*) but with the transformer tappings altered to give 1,500 volts d.c. output. These curves demonstrate the maintenance of high efficiency over a wide range of load, and show clearly the economic advantage of high voltage d.c. output. The no-load losses in the respective cases are: (*a*) 7·6 kW.; (*b*) 6·5 kW.; (*c*) 8 kW. The maintenance of high efficiency on low load factor is a very important consideration.

Grid Control

The means by which the application of a negative voltage to a grid screening a certain anode can be used to delay the firing of that anode has already been explained (p. 1001 of this Supplement, June 1, 1934). By thus delaying the firing of each anode in turn the d.c. voltage can be reduced to any desired extent, and if a suitable negative voltage be maintained on all the grids the flow of current can be prevented at all anodes. This offers a valuable means of clearing a short-circuit almost instantly; the arc on the anode in action, at the moment of applying negative "blocking" potential to all the grids, must die down naturally (its positive ions meanwhile neutralising the negative potential applied to its grid), but the arc cannot then be taken over by any other anode. Further reference will be made later to this and other special applications of grid control.

The principal present use of grid control, and certainly the one of greatest interest where glass-bulb rectifiers are concerned, is that of voltage control. The d.c. voltage may be altered by changing the tappings of the a.c. transformer, but this gives discontinuous step-by-step control. An induction-regulator provides for continuous

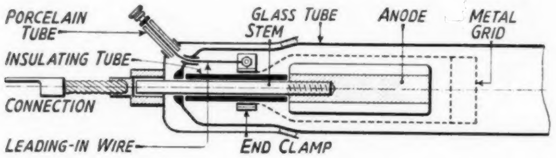


Fig. 9—Sectional view of rectifier anode with control grid

gradation of a.c., and therefore of d.c. voltage within a prescribed range. However, grid control is yet more flexible and efficient, and is specially adaptable to automatic control, whether in main traction supply or in connection with lighting, battery charging, or other auxiliary services.

The illustration of an English Electric rectifier bulb, in Fig. 8, shows clearly the perforated sheet control grids in position round the main anodes. The constructional details of such an arrangement are shown by Fig. 9. The anode is carried by the stem which is fused through the glass tube and connected to the connection. The grid of perforated metal sheet completely surrounds the anode and is clamped on to the insulating tube. Electrical connection to the grid is made by the leading-in wire, fused through the glass and taken to a binding post through the porcelain tube, carried by a shield which protects the seals against mechanical stress.

In order that the firing of the anodes may be timed accurately by grid control, regardless of variations in load and temperature, it is advantageous to obtain hard control by giving the grid an impulse charge at the appropriate moment, in excess of the minimum voltage. This may be applied by means of a synchronously rotating contact maker, as explained on pages **1002-3**, June **1**, **1934**, or by a purely static device which is specially recommended for automatic voltage compounding as required by traction loads. As applied to English Electric rectifiers, this system uses specially-wound, highly-saturated auxiliary transformers, one for each anode-grid. The secondary of each transformer is connected in the lead from the negative bias battery to the corresponding grid. Normally, the transformer core is fully saturated by the magnetising effect of the primary windings. While this condition persists, there is no e.m.f. induced in the secondary winding and the grid remains negatively charged. When, however, the primary flux passes through zero, the sudden *reversal* of flux induces a considerable e.m.f. in the secondary winding. There are two of these kicks in each complete cycle of the magnetising current, which is derived from the a.c. supply. One of the kicks is a negative voltage which simply increases the negative bias of the grid; the other is a positive voltage which overcomes the negative bias due to the battery and fires the anode. In order to alter the timing of the voltage kicks, and hence the timing of the firing of the anodes and the value of the d.c. voltage delivered by the rectifier, there are two primary windings on each transformer, and the phase of the current in one winding is varied to alter the moment at which the resultant flux reverses.

What is claimed to be the largest installation of grid-controlled rectifiers in the world is a multiple-unit bank of Hewittic glass-bulb rectifiers of **3,500** kW. capacity supplying the Perth (Scotland) **500**/**250**-volt d.c. network, and there is little doubt that grid-control will rapidly become standard practice in all mercury rectifiers on fluctuating loads. Its utility is likely to be particularly apparent in traction service, and also to extend to supplies for station hotels, goods depots, and workshops. In view of the increasing use that is being made of welding in the building of rolling stock, it may be mentioned that grid-controlled rectifiers have proved useful in timing the current impulses in seam and spot welding machines. Other subsidiary uses for grid-controlled glass-bulb rectifiers are in charging accumulators for shunting locomotives, and as a stand-by source of d.c. instead of a storage battery.

The question of smoothing the wave form of the d.c. delivered by a mercury rectifier is one which is still a subject of controversy. The ripples or harmonics in the d.c. wave tend to become more pronounced when the voltage is reduced by grid-control. Technically their removal offers no great difficulty, but it is as well to confirm the actual degree of telephonic or other disturbance caused by the harmonics before incurring the cost of special filter circuits. A choking coil in the cathode lead has a pronounced smoothing effect at all but light loads.

Fig. 10—Two 120 kw. English Electric glass-bulb rectifier cubicles

ELECTRIFICATION OF CENTRAL OF BRAZIL RAILWAY

Additional particulars of important conversion, the contract for which has been awarded to a British firm

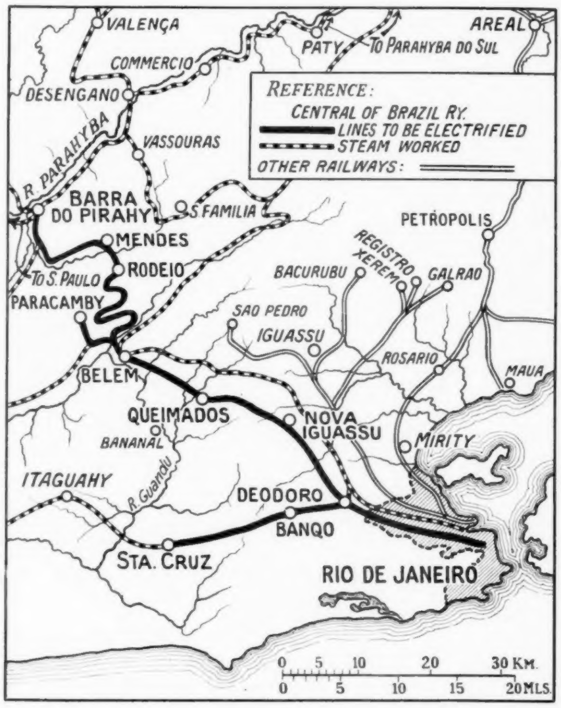
As recorded in the issue of this Supplement for June 1, the contract for the electrification of certain lines round Rio de Janeiro belonging to the Central Railway of Brazil was recently signed by the Brazilian President, Dr. Getulio Vargas, and the Metropolitan-Vickers Electrical Co. Ltd. The project has been under consideration for a long time; but opposition from the Brazilian Exchequer has delayed the completion of the negotiations, although that department acknowledged that the work was urgent, as the existing traction system could no longer cope with the traffic. The scheme for financing the conversion was described on page 997 of our June 1 issue.

The routes to be converted are the suburban lines out of Rio de Janeiro to Deodoro and Santa Cruz, and the main line from Deodoro to Barra do Pirahy. A preliminary investigation showed that the cost of electrifying these lines was so little more than the amount which would be required to construct new locomotives and stock, re-model the stations, signals, and shops, and generally bring the steam service thoroughly up to date, that there was no justification for not proceeding with electrification. The estimates indicated that the amortisation of the whole electrification cost could be effected in eight years, but the Minister of Finance expressed the opinion that the Central Railway was not sufficiently equipped for fulfilling its purpose, and whether the suburban lines were electrified or not, a large investment of capital was necessary to meet its deficiencies.

Most conclusive and cogent arguments have been put forward for the conversion, principal among which are the reduced cost of operation and the greater facilities which can be offered to the public. According to data based on an average year's working, the annual cost of steam operation between the Rio terminus, Dom Pedro II, and Santa Cruz and Barra do Pirahy, including branches, amounts to 31,343 contos. With electrification this figure should be reduced to 17,254 contos, while it is further expected that once electric operation is in full swing, an increased revenue of 2,000 contos per annum will be obtained, making a total saving of over 16,000 contos.

In 1932 the suburban trains on the above broad-gauge lines covered 3,856,032 km., compared with 725,106 km. in 1900, and the increase in passengers was in almost exact proportion, totalling 62,589,829 against 11,958,759. Yet in order to provide the necessary trains for the transportation of this vast number of passengers, the total number of vehicles had been increased merely from 165 in 1900 to 274 in 1932, and the great majority of the coaching stock now in use is over 35 years old. The whole traffic over the lines to be converted represents 40 per cent. of the train movement over the 5 ft. 3 in. section of the Central Railway, and the transportation of fuel to the various supply points represents 12 per cent. of the total movement. 13,070 wagons of coal, most of which was imported, were worked in 1,188 trains over an average distance of 164 miles in the course of the year 1932.

The electrification scheme provides for the conversion to the 3,000-volt direct current system of 93·5 route miles, and 232 track miles inclusive of sidings and the lines at Maritima dock, as shown on the accompanying map. It is expected that five rectifier substations with a total capacity of 25,500 kW. will be installed to convert high-tension three-phase current to the line voltage. The urban and suburban services between Dom Pedro II station in Rio and Deodoro will be served by three-car trains consisting of one motor-coach and two trailers. From Deodoro, the lines to Santa Cruz and Barra do Pirahy, including the Paracamby spur, will be served by electric locomotives hauling ordinary coaches and wagons, which will be taken over by steam locomotives at the above-mentioned points. The Metro-Vick electro-pneumatic



Map of lines to be electrified on the Central of Brazil Railway

system of control will be used throughout, and pantographs will be used to collect the current from the overhead catenary suspension. Fully automatic and power-controlled all-electric signalling is also included in the contract, and the apparatus will be of the type supplied by the General Railway Signal Co. Ltd., of London, and manufactured at the Trafford Park works of the Metropolitan-Vickers Electrical Co. Ltd. The apparatus will incorporate the most modern improvements in the principles and practice of electric signalling as developed by the two firms associated in its manufacture.

Russian Express Electric Locomotive.—A new electric locomotive with an output of 2,700 h.p. and a top speed of 81 m.p.h., which has been built throughout in Russia, has been tested on the Moscow–Sagorsk line, and will eventually go into service on the Ekaterinski Railway.